MULTIYEAR SEA ICE THICKNESS ESTIMATION USING WIDEBAND P/L-BAND RADIOMETRIC MEASUREMENTS

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IGARSS 2019 WE3.R10: Microwave Radiometer Instruments and Calibration I

Jet Propulsion Laboratory
California Institute of Technology

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Background

Sea ice plays an important role in regulating exchanges of heat, moisture, and salinity in the polar oceans and ultimately in the global climate.

Monitoring the seasonal Arctic and Antarctic sea-ice thickness is key to understanding the heat flux between air and ocean surface as well as salt and fresh water fluxes between ocean and the frozen surfaces.

Ice thickness, its spatial extent, and the fraction of open water within the ice pack can vary rapidly and profoundly in response to weather and climate.

Sea Ice thickness information will help understanding the variations on sea ice extent and concentration.

Sea Ice concentration maps showing the lowest September minimum Arctic sea ice extents

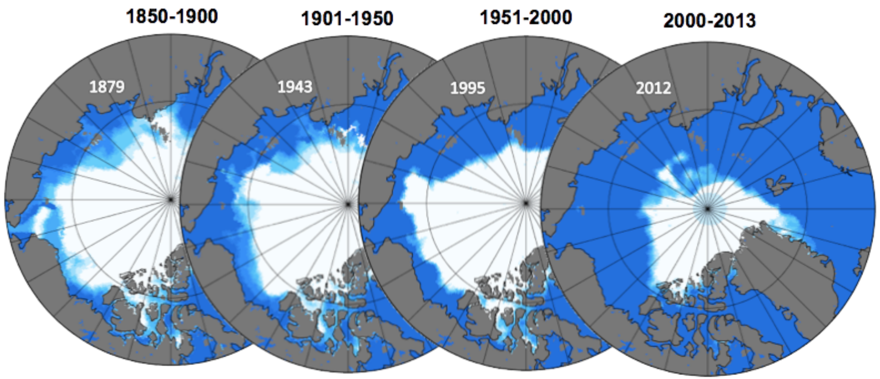

Image credit to F. Fetterer/National Snow and Ice Data Center, NOAA

Goal

Develop an instrument that uses combined P-/L-band radiometric measurements

Understand the wide-band calibration challenges.

Test the instrument during a field campaign on board the US Coast Guard Cutter Healy over the Arctic to:

- Study the dual band properties of the measurements to infer sea ice thickness.
- Study the wideband spectral properties of salinity.

Goal

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Understand the wide-band calibration challenges:

Mehmet Ogut, et al., THE CALIBRATION AND STABILITY ANALYSIS OF THE JPL ULTRA-WIDE P/L-BAND RADIOMETER
WEP2.PN: Microwave Radiometer Instruments and Calibration II, Poster Area N, Wednesday, July 31, 15:20 - 16:20

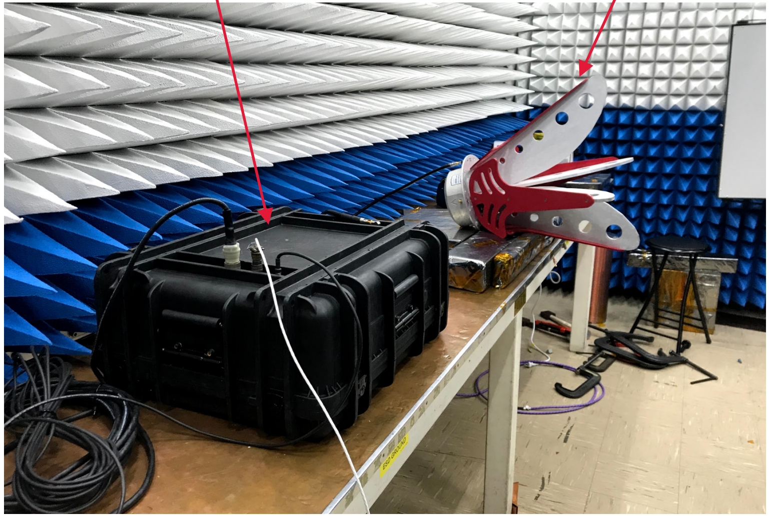
Test the instrument during a field campaign on board the US Coast Guard Cutter Healy over the Arctic to:

- **Study the dual band properties of the measurements to infer sea ice thickness**.
- Study the wideband spectral properties of salinity:

Sidharth Misra, et al., A NEXT GENERATION MICROWAVE RADIOMETER FOR COLD WATER SALINITY MEASUREMENT
WE4.R10: Microwave Radiometer Instruments and Calibration IV, Room 418, Wednesday, July 31, 16:20 - 18:00

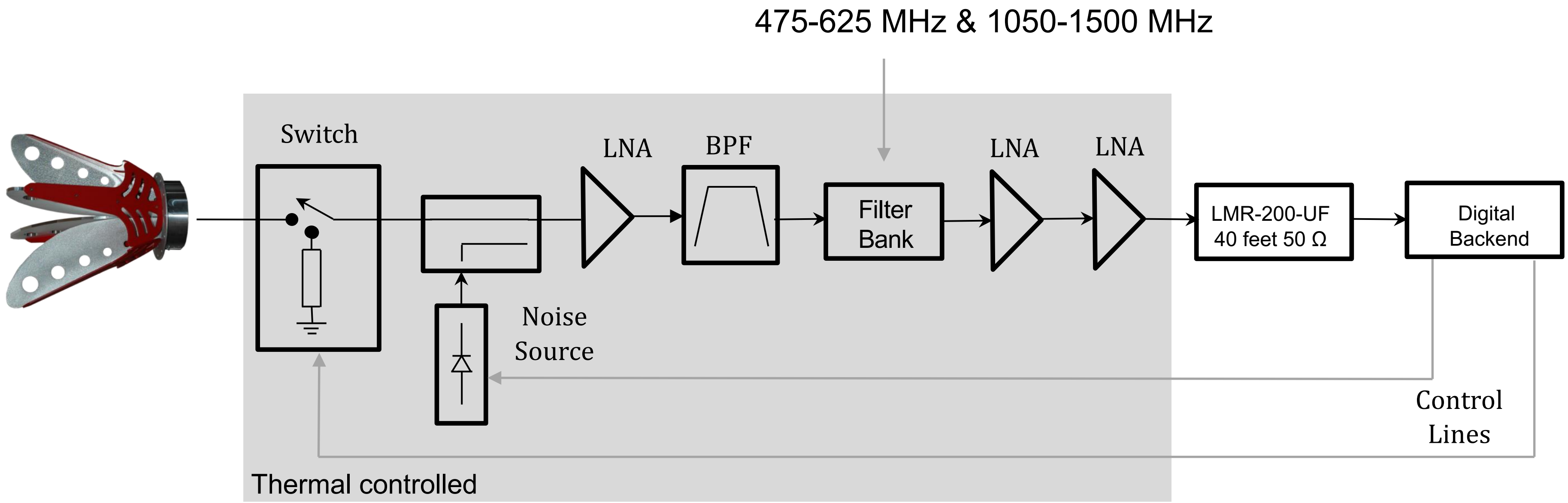
Instrument Description

1. Sampling of signals with several GHz of bandwidth
   - ADC and FPGA technology development
   - 8-bit ADC with a first Nyquist image at 3.2 GHz sampling rate allowing a total sampling bandwidth of 1.6 GHz
2. Active Thermal control
3. A wideband quad-ridged antenna
4. LNA and a filter bank is applied to prevent receiver saturation by RFI. Filter bank set-up to allow P-band and L-band measurements.
   - 475-625 MHz (P-band, total 384 channels)
   - 1050-1500 MHz (L-band, total 1154 channels)
5. FPGA acquisition:
   - 4096-channel spectrogram using polyphase filter FFT algorithm



Ultra wide band instrument being tested at a JPL EMC facility

Bloc diagram



Instrument Description

Signal Processing Chain

1. Sampling of signals with several GHz of bandwidth
    - ADC and FPGA technology development
    - 8-bit ADC with a first Nyquist image at 3.2 GHz sampling rate allowing a total sampling bandwidth of 1.6 GHz
2. A wideband quad-ridged antenna
3. Coupler for a noise diode input and a Dicke switch
4. Low noise amplifier (LNA) and a filter bank is applied to prevent receiver saturation by Radio Frequency Interference (RFI). Filter bank set-up to allow P-band and L-band measurements.
    - 475-625 MHz (P-band, total 384 channels)
    - 1050-1500 MHz (L-band, total 1154 channels)
5. Signal sent to a digitizer (8-bit)
6. FPGA acquisition:
    - 4096-channel spectrogram using polyphase FFT filter.

Instrument Description

Processing to final T_A

Final Tsys = 500 K for the whole bandwidth and each individual channel bandwidth 390 kHz

Channels with excessive RFI presence discarded.

Remaining channels within each band (P- or L-) are combined together reducing noise.

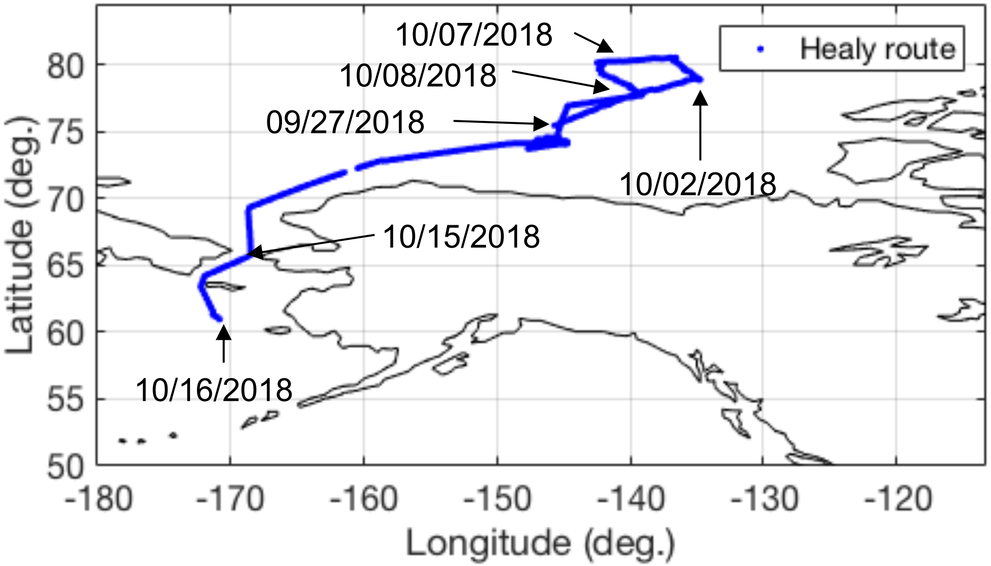
Antenna temperature is calculated for science applications

Field Experiment Set-Up

The wideband P/L-band radiometer was installed in the ship on September 12, 2018.

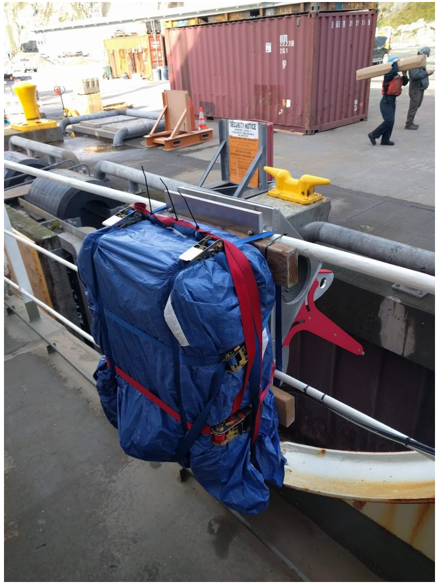
Expedition took 37 days from Dutch Harbor, Unalaska Island, AK, to the Bearing Sea, crossing the Chukchi Sea through the Bering Strait and up to the Beaufort Sea to a maximum latitude of 82° N and returning back.

US Coast Guard Cutter Healy



Field Experiment Set-Up

The wideband radiometer was installed on the back of the cruise ship, on the left side attached to the railing and pointing to the sea surface at 45° incidence angle.

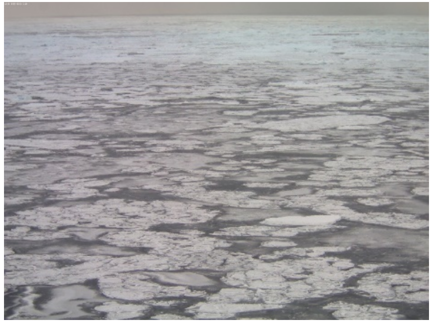


Measurements:

- Ultra-wide band Radiometer: 14h/day
- 2 thermosalinographs: SST and SSS every 14s.
- Ice type and thickness information recorded in a digital log.
- A picture of the scene was taken every 60s.

Image of multi-year ice during the cruise

Image of pancake ice during the cruise



Calibration

Calculated for each channel

(1) $V_{ANT} = (T_{ANT} + T_{REC} + \Delta T_{ANT})/m_1 \cong (T_{ANT} + T_{REC})/m_1$

(2) $V_{REF} = (T_{REF} + T_{REC} + \Delta T_{REF})/m_2 \cong (T_{REF} + T_{REC})/m_2$

$\rightarrow$

$$T_{ANT} = m_1 V_{ANT} - T_{REC}$$
$$T_{REC} = m_2 V_{REF} - T_{REF}$$

$\boldsymbol{m_1}$ and $\boldsymbol{m_2}$ are unknowns that account for antenna & reference mismatches

(3) $V_{ANT\_ND} = (T_{ANT} + T_{ND} + T_{REC} + \Delta T_{ANT\_ND})/m_1 \cong (T_{ANT} + T_{ND} + T_{REC})/m_1$

(4) $V_{REF\_ND} = (T_{REF} + T_{ND} + T_{REC} + \Delta T_{REF\_ND})/m_2 \cong (T_{REF} + T_{ND} + T_{REC})/m_2$

$[(3) - (1)]: V_{ANT\_ND} - V_{ANT} = T_{ND}/m_1$

$[(4) - (2)]: V_{REF\_ND} - V_{REF} = T_{ND}/m_2$

$\rightarrow$

$$m_1 = \frac{T_{ND}}{V_{ANT\_ND} - V_{ANT}}$$
$$m_2 = \frac{T_{ND}}{V_{REF\_ND} - V_{REF}}$$

Assuming noise source ENS constant, then m_1 and m_2 are calculated

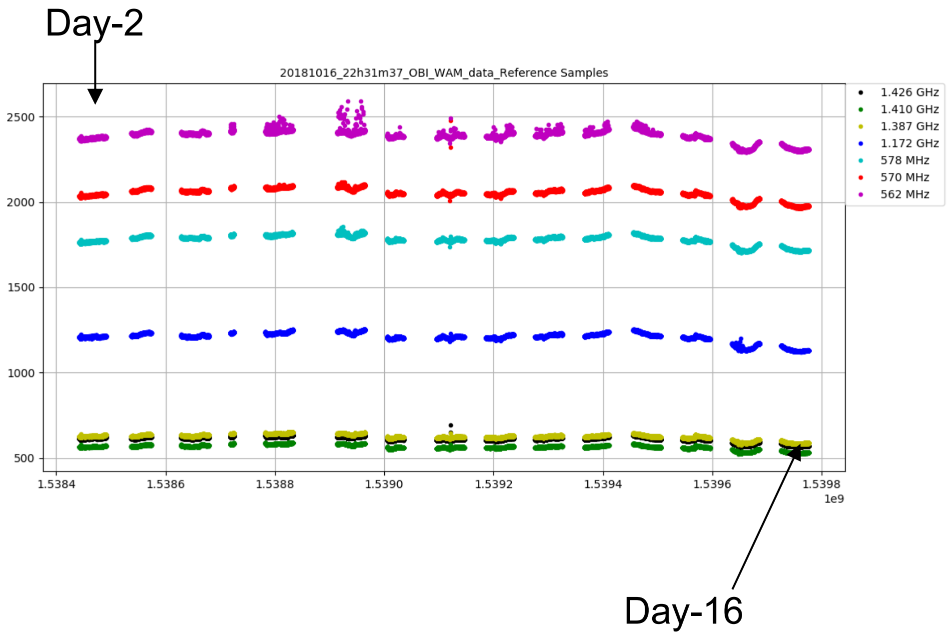
$$T_{ANT} = m_1 V_{ANT} - T_{REC} = m_1 V_{ANT} - (m_2 V_{REF} - T_{REF}) = \frac{T_{ND}}{V_{ANT\_ND} - V_{ANT}} V_{ANT} - \frac{T_{ND}}{V_{REF\_ND} - V_{REF}} V_{REF} + T_{REF}$$

$$\boxed{T_{ANT} = T_{ND}\left(\frac{V_{ANT}}{V_{ANT\_ND} - V_{ANT}} - \frac{V_{REF}}{V_{REF\_ND} - V_{REF}}\right) + T_{REF}}$$

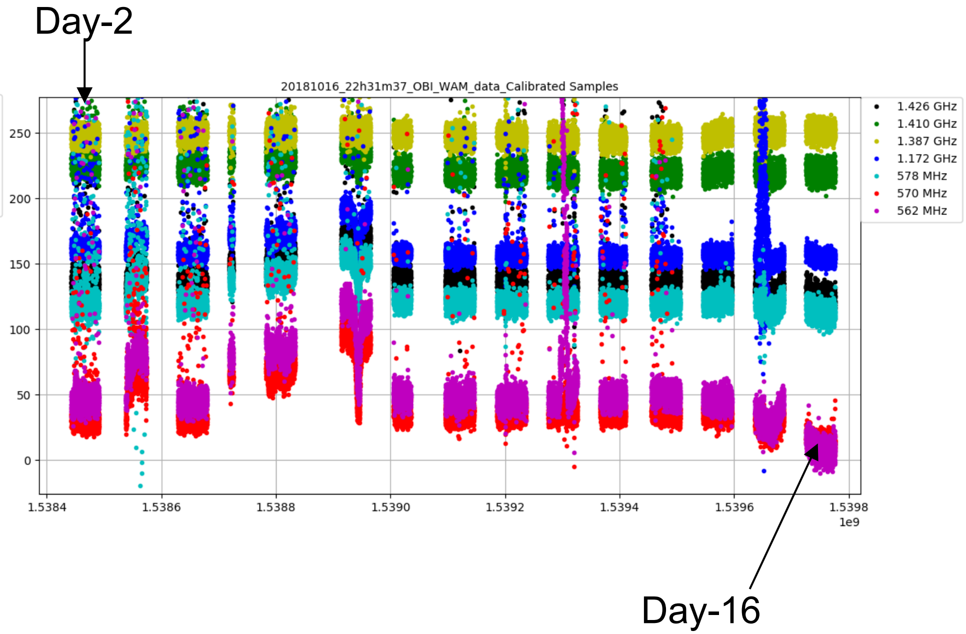
The calibration relies on the stability of the noise diode (T_{ND}) and the reference load (T_{REF}).

Calibration

Reference Samples

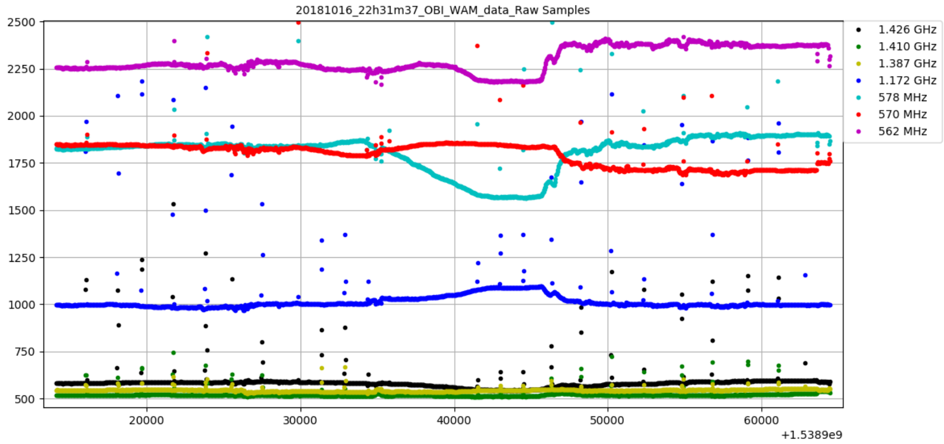


Calibrated Antenna Samples

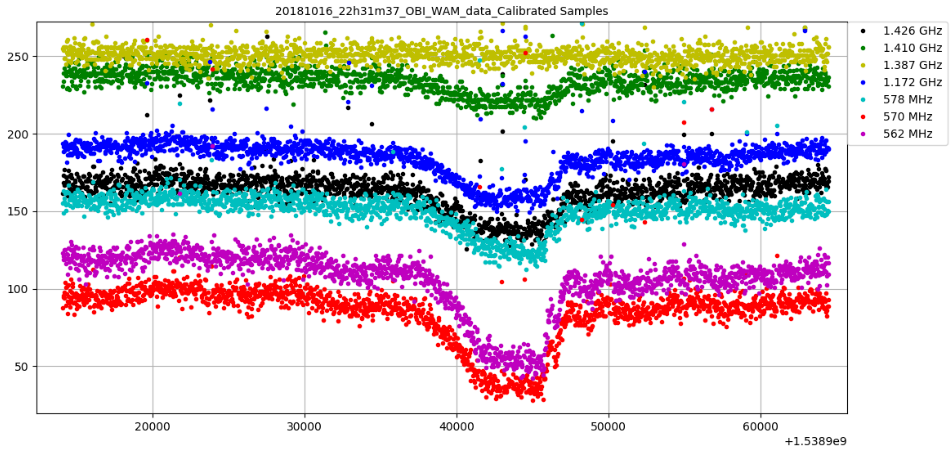


Calibration

Raw Uncalibrated Samples: Day 7



Calibrated Antenna Samples: Day 7



Results

Channels selected:

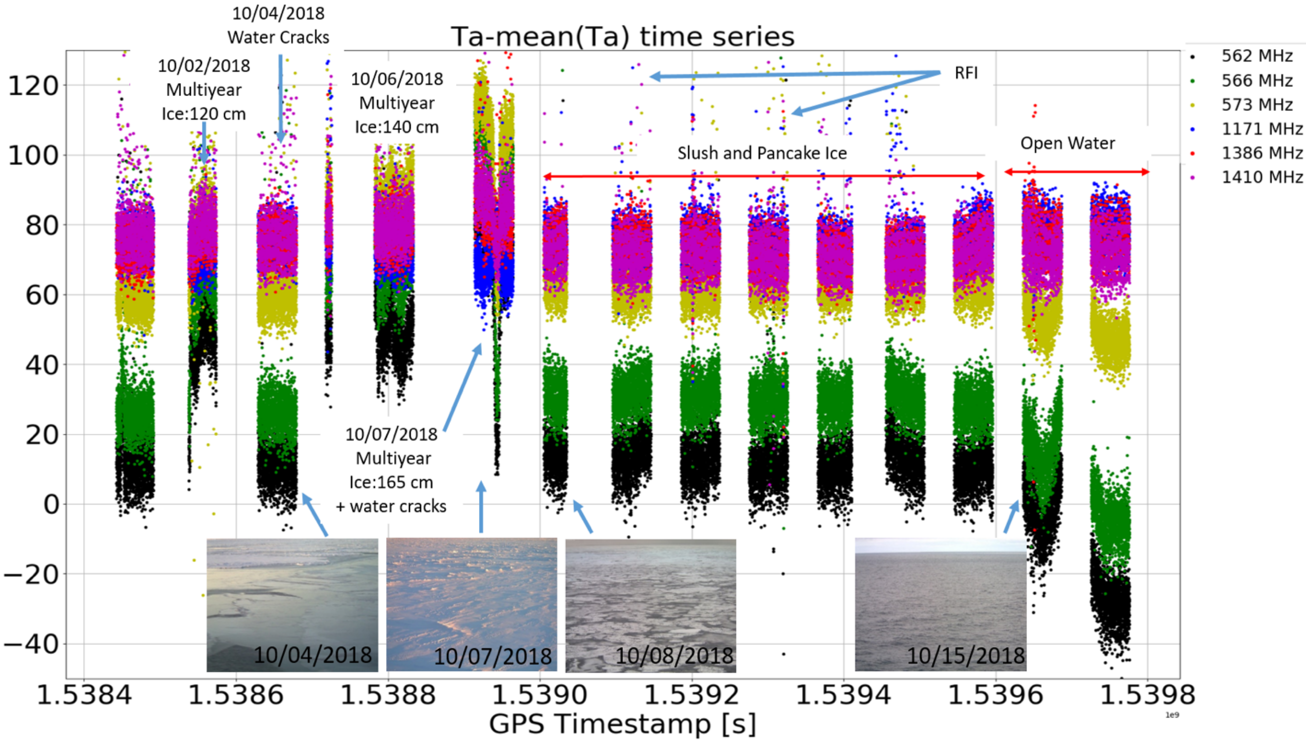
- P-band 542, 566, and 573 MHz
- L-band, 1171, 1366 and 1410 MHz
- 3.9 MHz bandwidth/channel

Analysis:

October 1, 2019 (Day 1) to October 16, 2019 (Day 16).

Observations:

P-band channels show an increase on the TA – mean(TA) value when sea ice is present. The thicker the sea ice the higher the computed values. L-band seems not responsive to ice sheet thickness remaining almost unchanged.



Conclusions

A wideband P/L-band radiometer has been built and deployed on board the US Coast Guard Cutter Healy while cruising from the Bearing Sea to the Beaufort Sea.

- The primary objective of the field campaign was to assess empirical dependence of cold-water sea surface salinity from P/L-band measurements

- The secondary objective of the field campaign is to assess sea ice thickness estimations from the multi-band measurements.

During this campaign, the vessel encountered several types of ice: multi-year and slush and pancake ice.

Multi-year ice thickness observed from 120 cm to 350 cm.

A clear relationship between multi-year ice thickness and P-band and L-band measurements was observed.

Future Work

- Refine the calibration to account for galactic noise, foam, sea roughness.
- Detect improvements required in the instrument, if any.
- Plan a second field experiment to obtain more measurements and extra characterization of the observed surface through more detailed in-situ measurements of the ice conditions.
- Explore the capabilities to become an instrument suitable for an airborne platform.
- Explore the science that radiometric multi-band measurements will allow under other environments, specially soil moisture developments.

Acknowledgements

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Thank you!

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